Tropical thin cirrus and relative humidity distributions observed by AIRS and other A-Train observations

by

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Motivation – 1

- **Results to be submitted:**
  - Kahn, B.H., C.K. Liang, A. Eldering, A. Gettelman, K.N. Liou, and Q. Yue (2007), Tropical thin cirrus and relative humidity distributions observed by the Atmospheric Infrared Sounder, *to be submitted to Atmos. Chem. Phys. Discuss.*

- **Cirrus and Earth's climate**
  - Climatic mean & variability (Ramanathan and Collins, 1991)
  - Extensive thin cirrus coverage
  - Radiative forcing several times larger than anthropogenic constituents
    - (e.g., McFarquhar et al. 1999; Comstock et al. 2002; Forster et al. 2007)
  - Hydrological cycle in UT (Baker, 1997)
    - Very small amounts of water have very large climatic impacts
  - Forcing, heating & feedbacks (Liou, 1986; Stephens, 2005)
  - UT/LS transport & chemistry (Holton et al. 1995)

Motivation – 2

- **Cirrus formation/maintenance uncertainties**
  - Unexplained observations of large ice S_i – some ideas:
    - Nitric acid at surface of ice prevents water vapor uptake (Gao et al. 2004)
    - Aerosols composed of organics (Jensen et al. 2005)
    - Lab measurements of small ice deposition coefficient (Magee et al. 2006)
    - Other ideas floated around
    - Nice summary in Peter et al. (2006)
  - Ice indirect effects poorly understood, observed, and modeled (Haag and Kärcher 2004)

- **AIRS and A-train provide new capabilities**
  - Other satellites limited to cirrus frequency and RH_i (e.g., Sandor et al. 2000)
  - AIRS provides:
    - Effective diameter (D_e) and optical depth (τ_{VIS}) (Yue et al. 2007)
    - UT RH_i (Gettelman et al., 2006)
  - Simultaneous observations of microphysics & RH_i

$\Rightarrow$ **A powerful combination with additional A-train observations**

Outline

- Thin Cirrus retrieval approach
- Results
  - Thin Cirrus retrievals
  - Joint distributions of thin Cirrus and humidity
- Take home messages
- Future work

Thin Cirrus retrieval approach – 1

- **Clear-sky radiances (OPTRAN) + thin Cirrus parameterization**
    - Approach of Yue et al. (2007) [in press, *J. Atmos. Sci.*]
    - Minimize observed + simulated radiances (14 channels from 8–12 μm)
    - Scattering models of Baum et al. (2007) (also used in MODIS Collection 5)

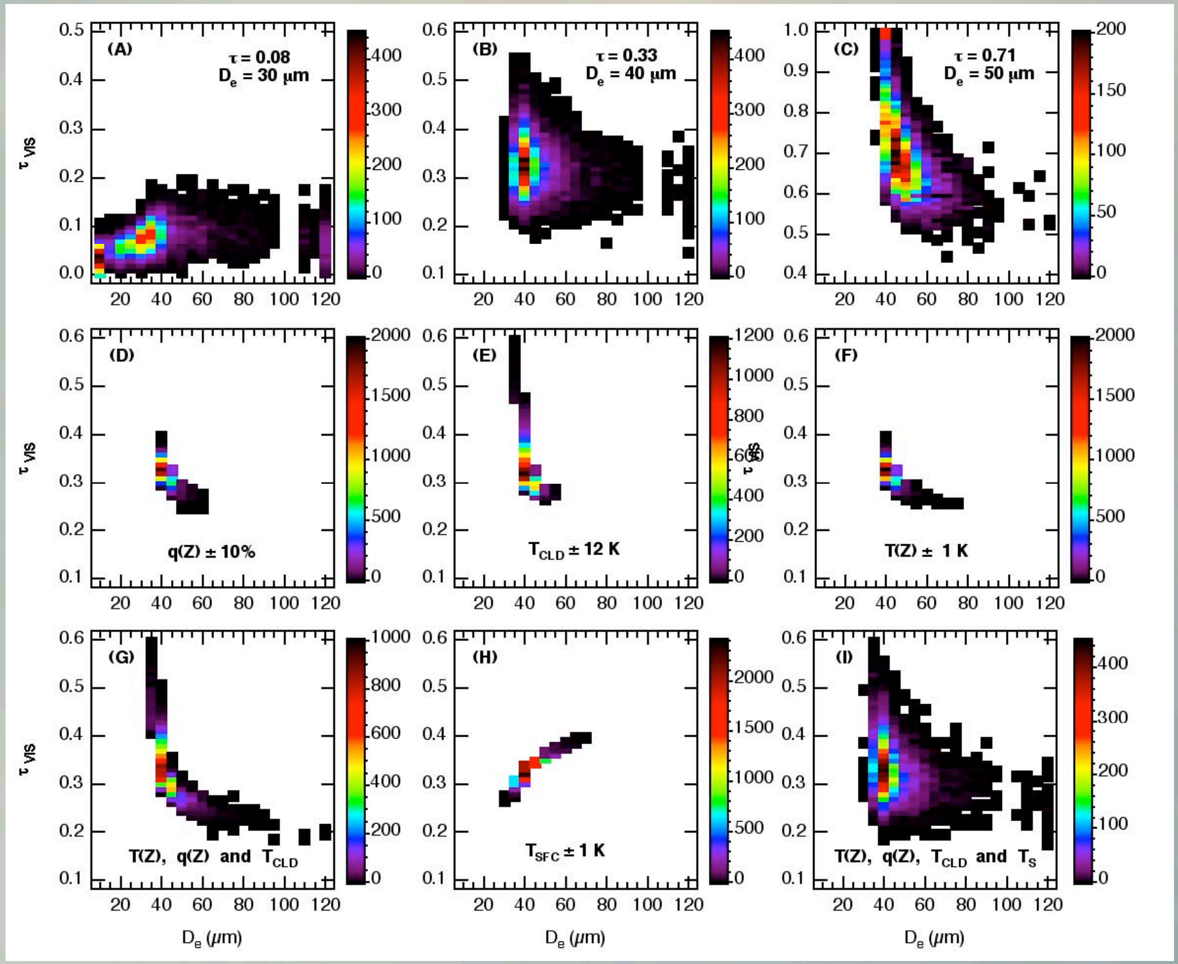
- **Details of retrieval approach:**
    - ~ 2.5 million single-layer thin Cirrus over oceans ± 20° lat
    - Applied to $0.02 \leq ECF \leq 0.4$
    - Valid for $0.0 < \tau_{VIS} \leq 1.0$
    - Dynamic effective size: $10\ \mu m \leq D_e \leq 120\ \mu m$
    - Land fraction < 0.1

Thin Cirrus retrieval approach – 2

- **Use AIRS L2 Standard & Support (V5):**
  - Cloud top temperature (T_C), amount, height, and detection validation studies:
    - Kahn, B. H., et al. (2007), Toward the characterization of upper tropospheric clouds using Atmospheric Infrared Sounder and Microwave Limb Sounder observations, *J. Geophys. Res*., **112**, D05202, doi:10.1029/2006JD007336.
    - Kahn, B. H., et al. (2007), The radiative consistency of Atmospheric Infrared Sounder and Moderate Resolution Imaging Spectroradiometer cloud retrievals, *J. Geophys. Res*., **112**, D09201, doi:10.1029/2006JD007486.
    - Kahn, B. H., et al. (2007), Cloud type comparisons of AIRS, CloudSat, and CALIPSO cloud height and amount, *Atmos. Chem. Phys. Discuss*., **7**, 13915-13958.
  - AIRS calculations of RH_i (Gettelman et al. 2004; 2006)
  - T(z) and q(z) V4 validation (Divakarla et al. 2006; Tobin et al. 2006; McMillin et al. 2007)

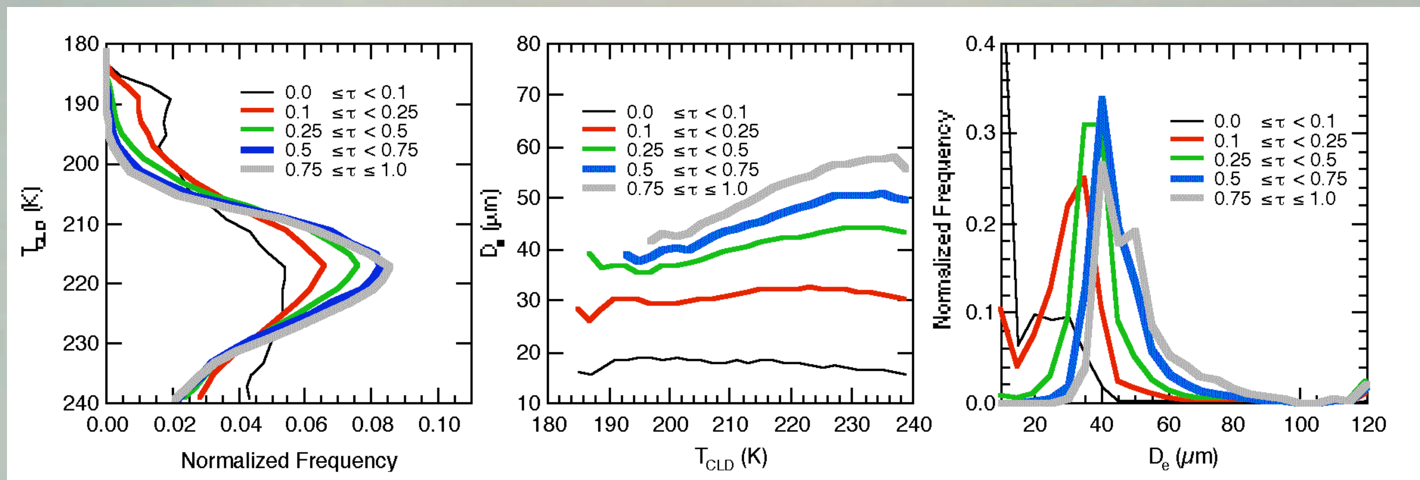
- **Validation studies used to explore biases in thin Cirrus τ and D_e**

Three case studies in thin Cirrus τ and D_e biases



T(z), q(z), T_C, T_S, ε and ρ using normally-distributed 1σ errors of ± 1 K, 10%, 12 K, 1 K, 0.01, and 0.01, respectively

Thin Cirrus T_C, τ and D_e consistent with other satellite, in situ, and surface obs



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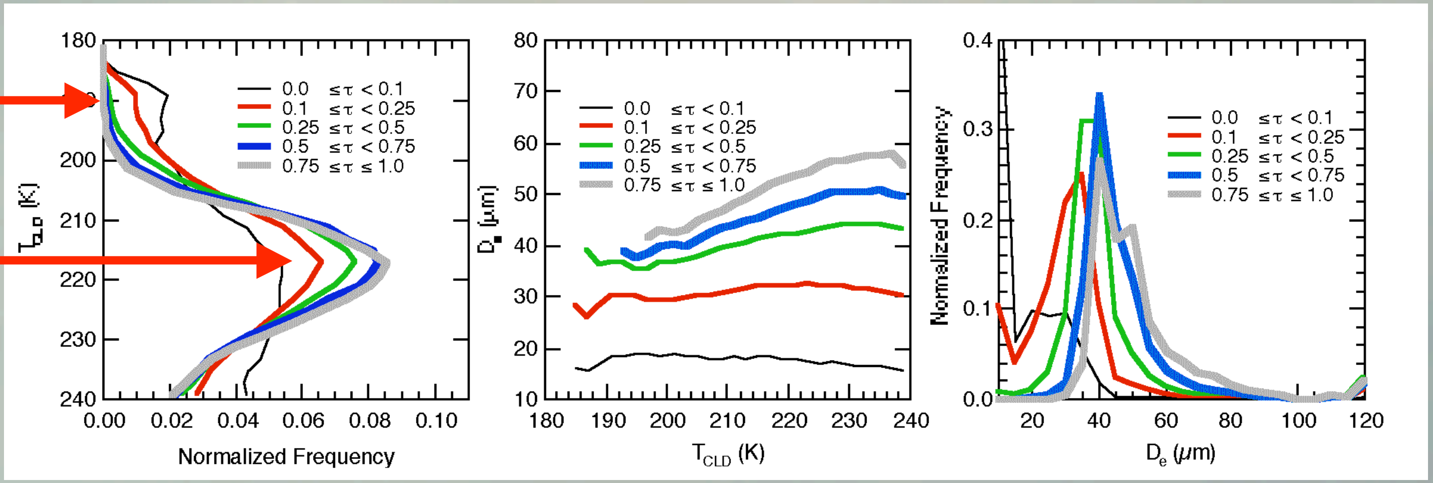
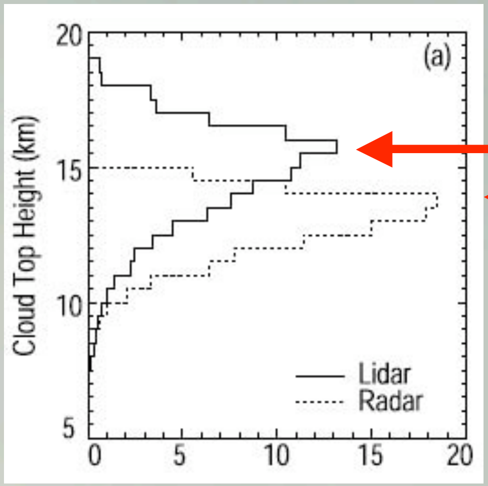
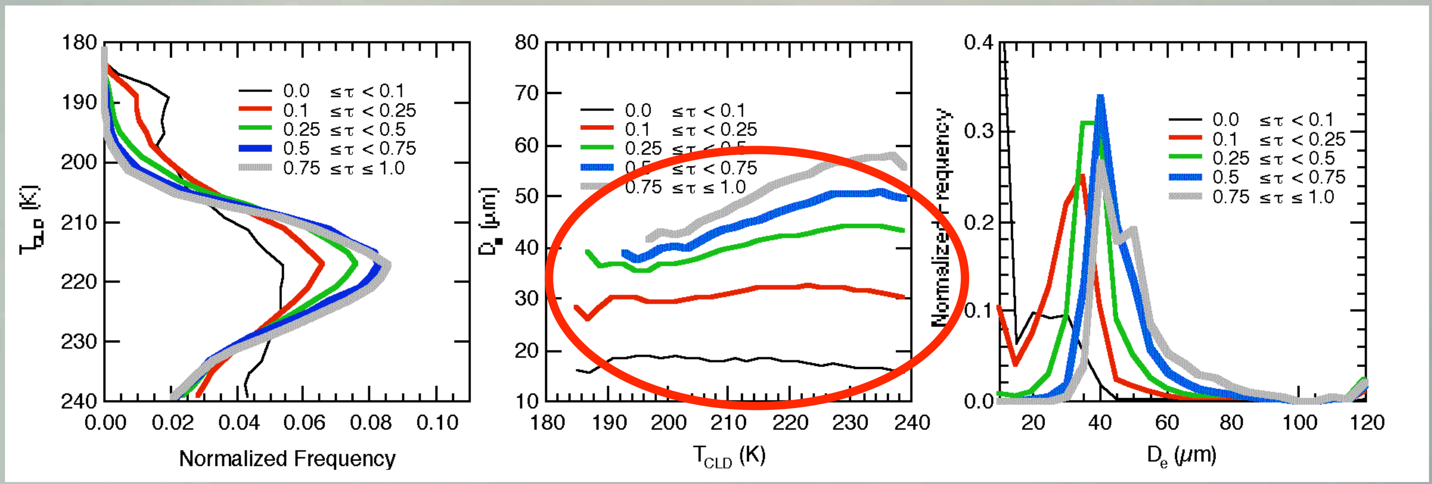
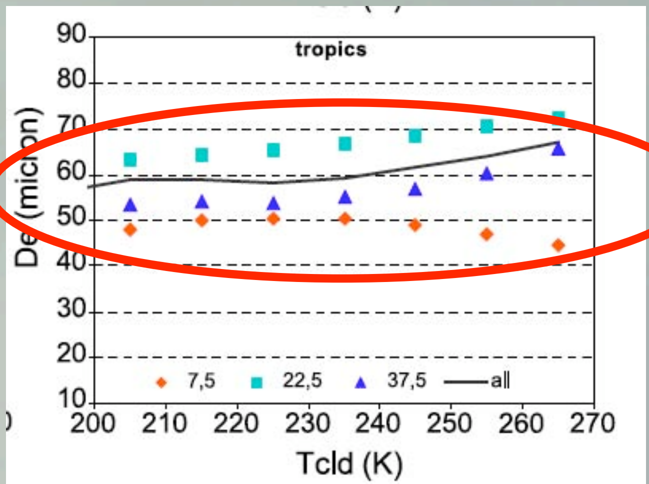




Comstock et al. (2004)

Thin Cirrus T_C, τ and D_e consistent with other satellite, in situ, and surface obs





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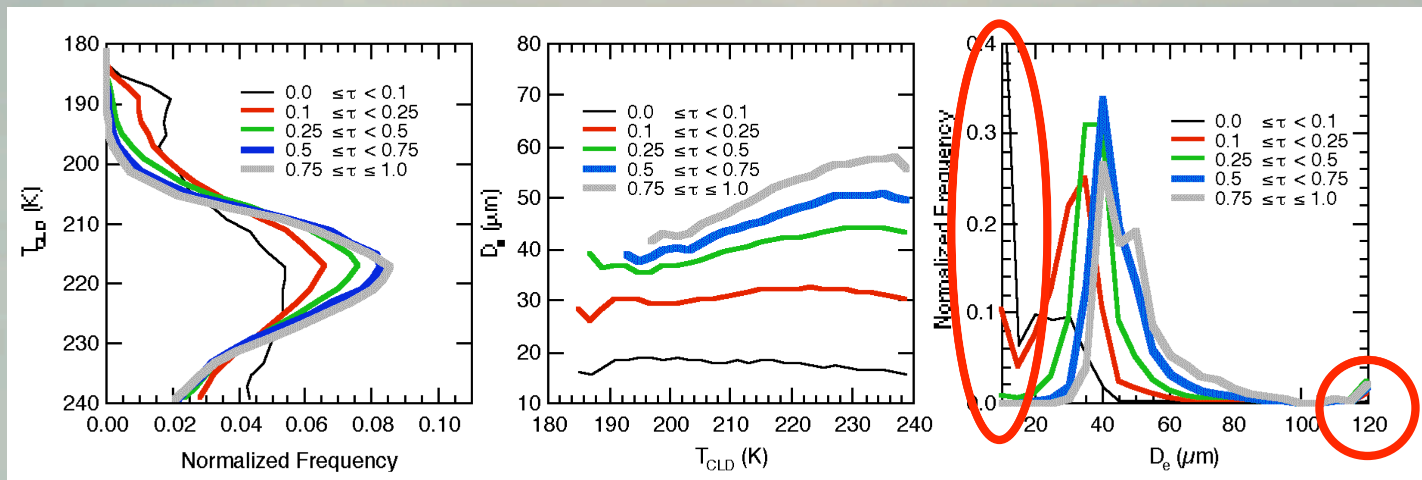
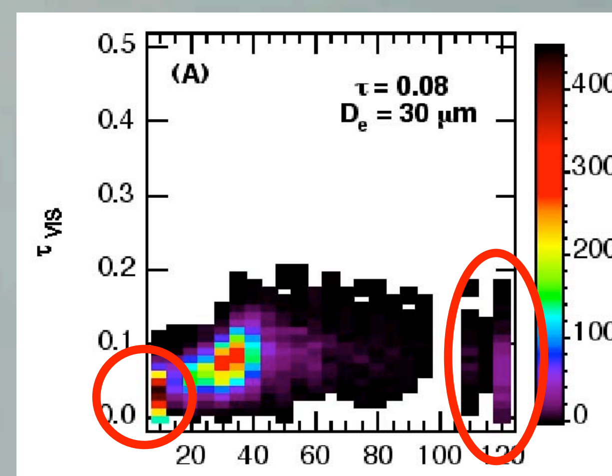
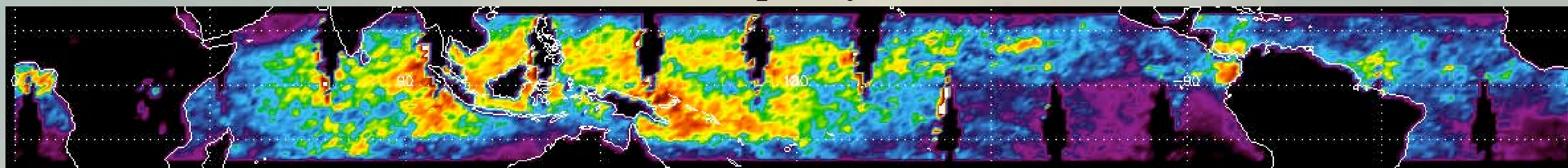


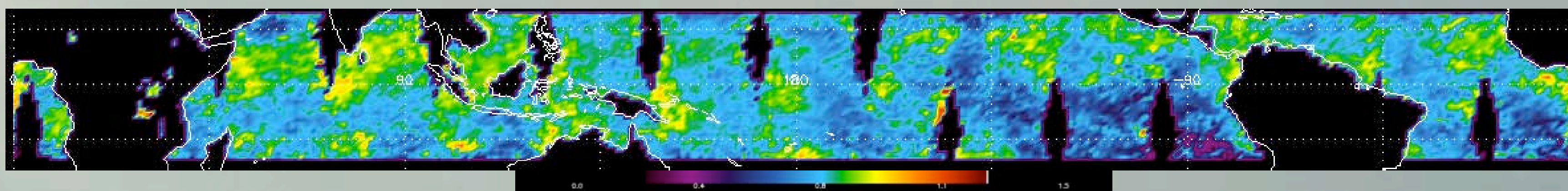


Annual average from focus days

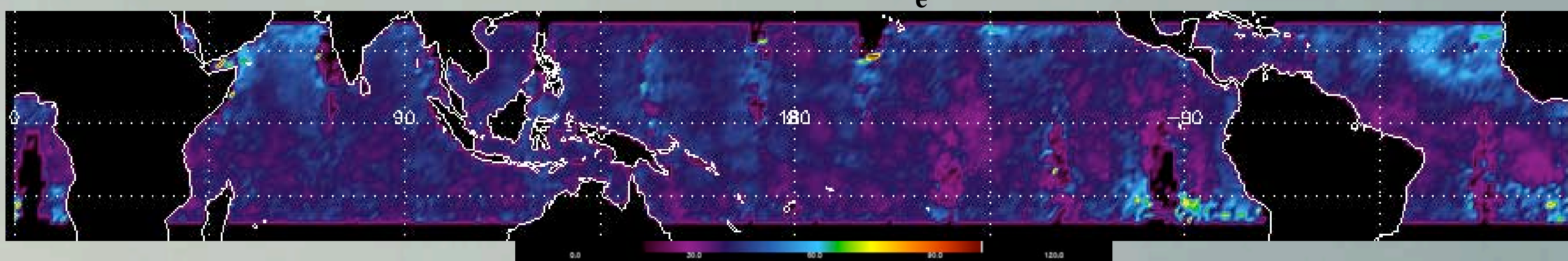
Thin Cirrus frequency with ECF ≤ 0.4



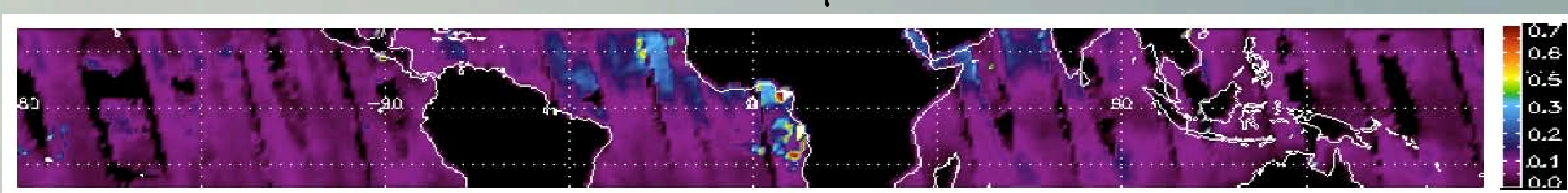
In-cloud RH_i



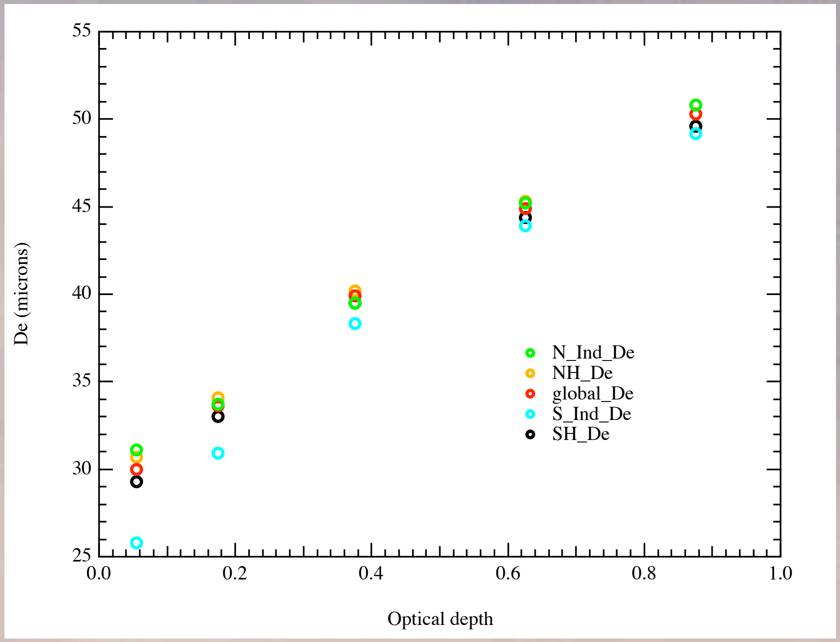
Thin Cirrus D_e



MODIS 2.13 μm aerosol τ



Inter-hemispheric differences in D_e: The importance of error estimates!

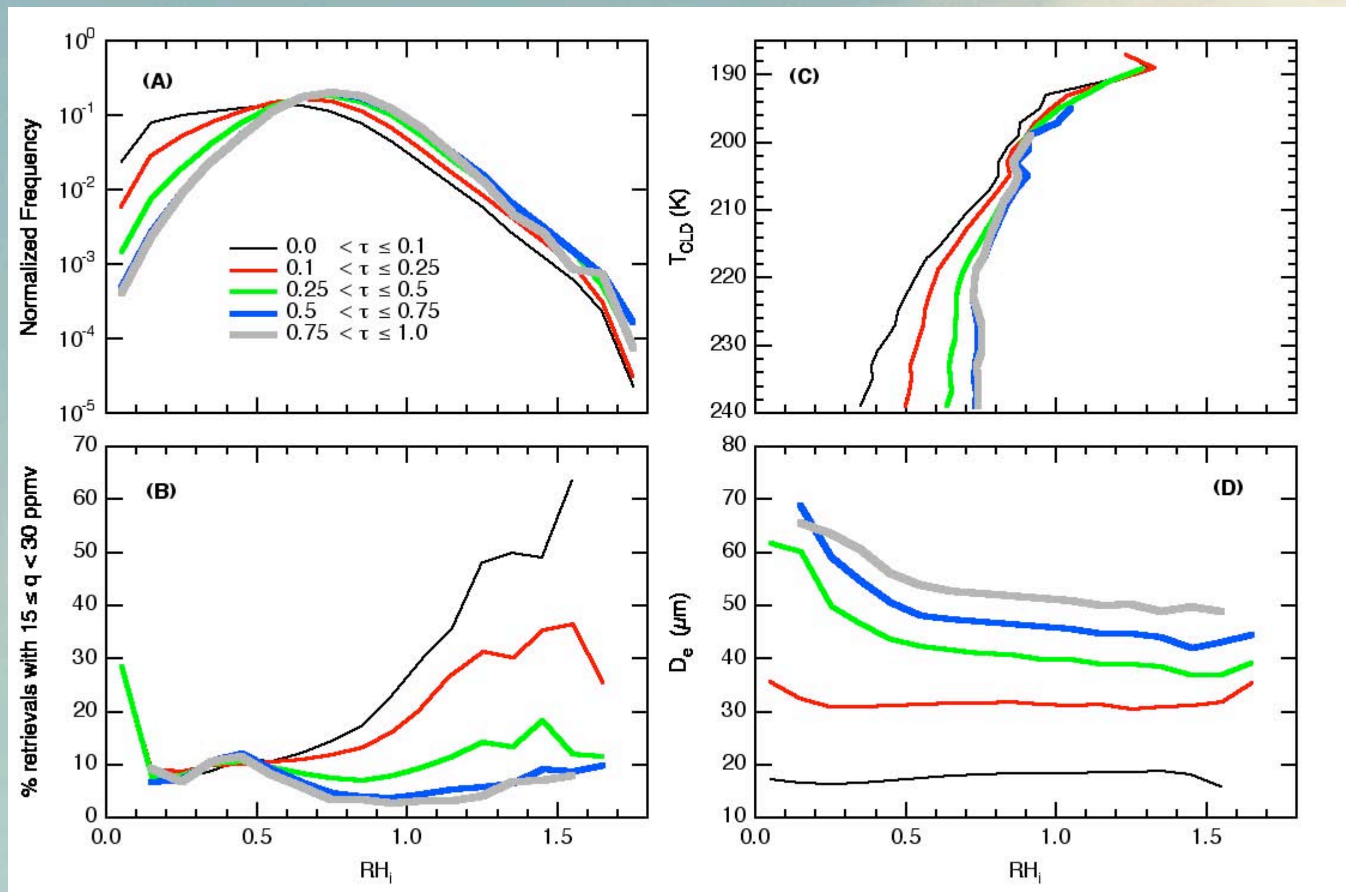


- Tantalizing regional differences in microphysics
    - Consistent with Kärcher (2004): heterogeneous ice nuclei in NH → larger D_e
- **BUT**, Statistical significance dependent on consideration of:
    - Error propagation (as in earlier figure), multi-layer clouds, aerosol (dust)

    ∴ Cannot make robust conclusion at this time

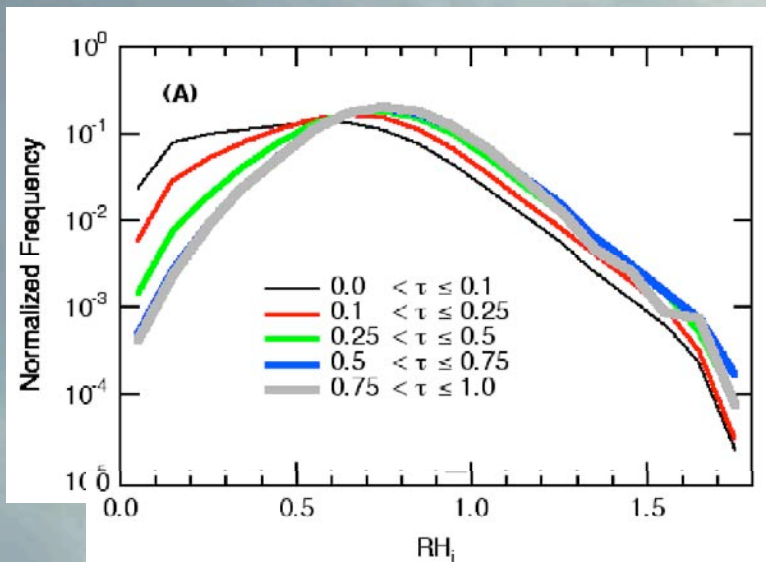
Joint distributions of thin Cirrus and humidity

Normalized frequency of RH_i **T_C versus RH_i**



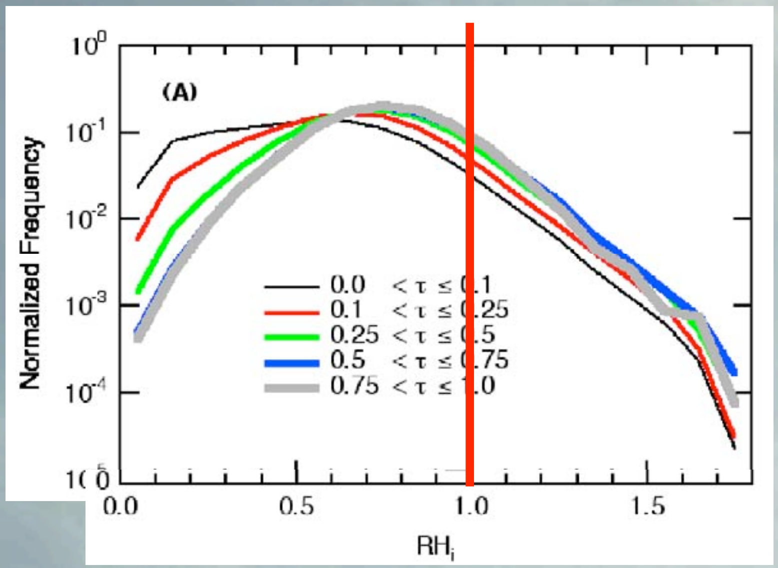
“Threshold” RH_i versus RH_i **D_e versus RH_i**

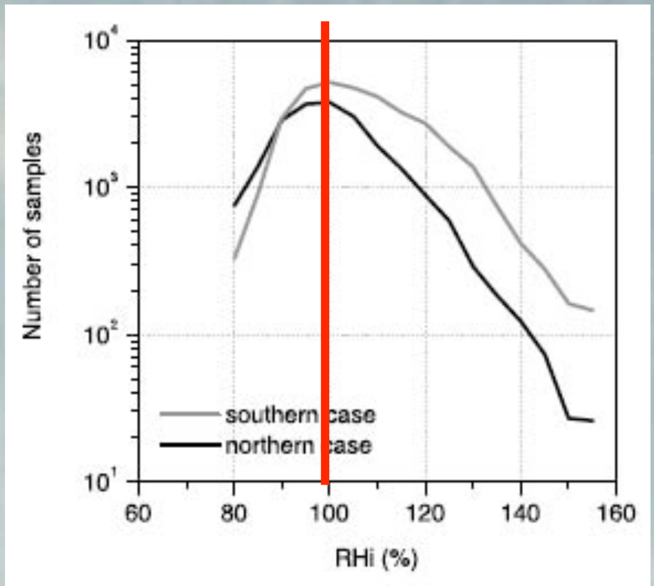
In-cloud RH_i vs. τ: What is correct?



- RH_i from Gettelman et al. (2006)
    - Globally 1–3% supersaturation in tropical UT
- In-cloud 8–12% supersaturation
    - More supersaturation in cloud than clear-sky

In-cloud RH_i vs. τ: Is it correct?

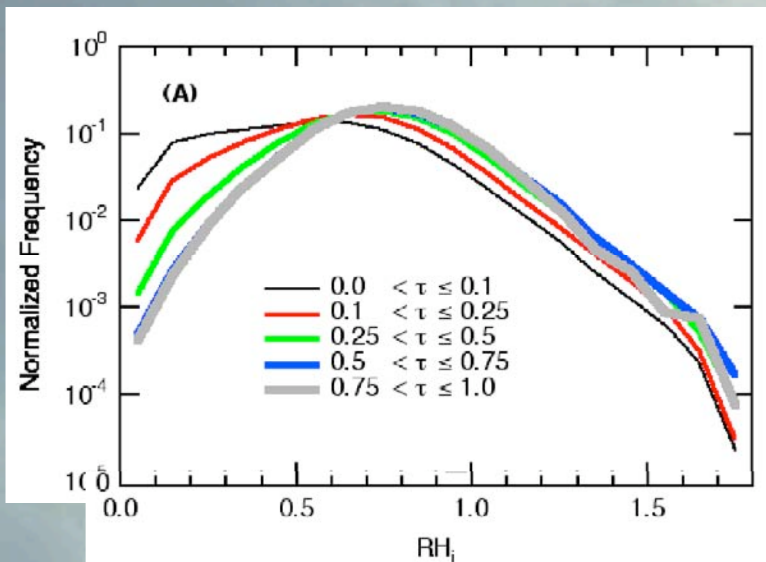


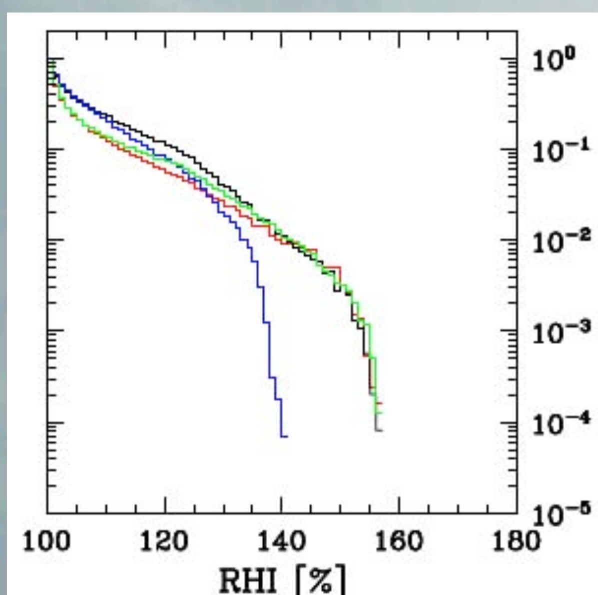


Gayet et al. (2004)

Observations from INCA campaign

In-cloud RH_i vs. τ: What is correct?



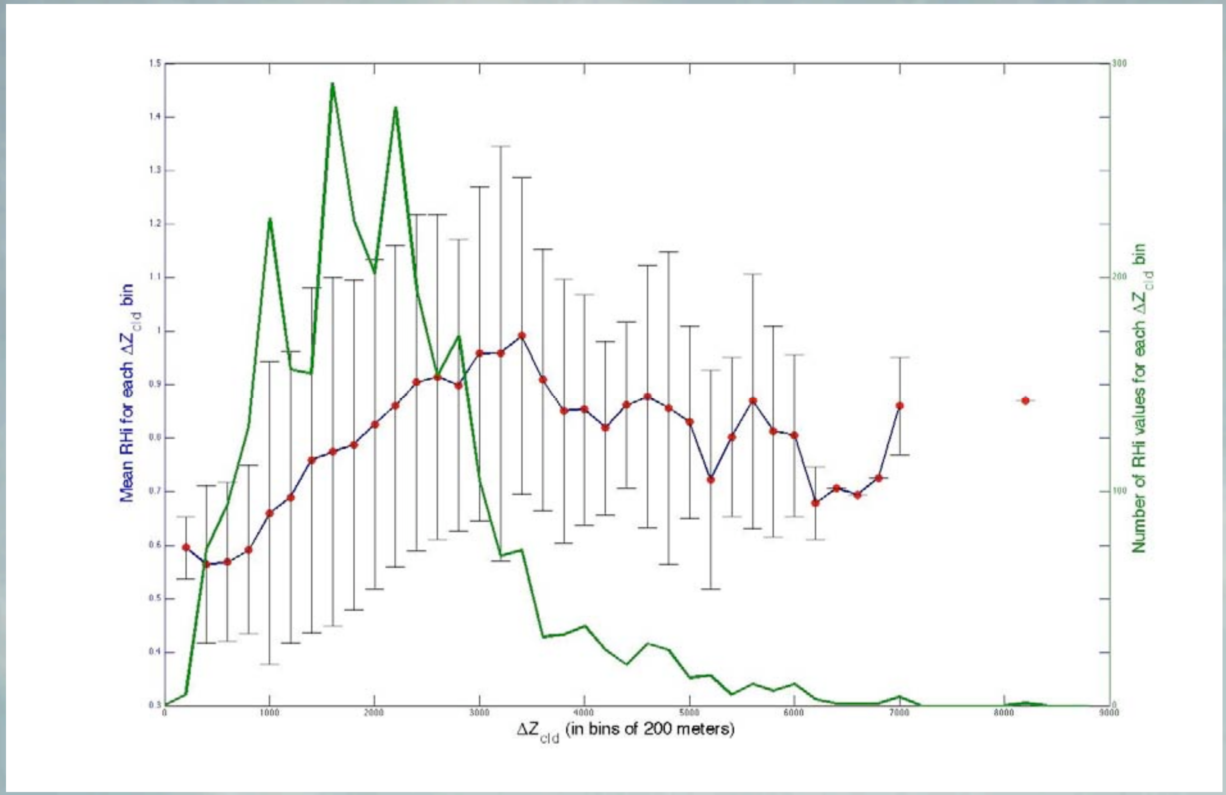


Haag and Kärcher (2003)

In-cloud supersaturation dependence on RHI

Calculations from a coupled parcel/trajectory model

Are cloud thickness and in-cloud RH_i related?

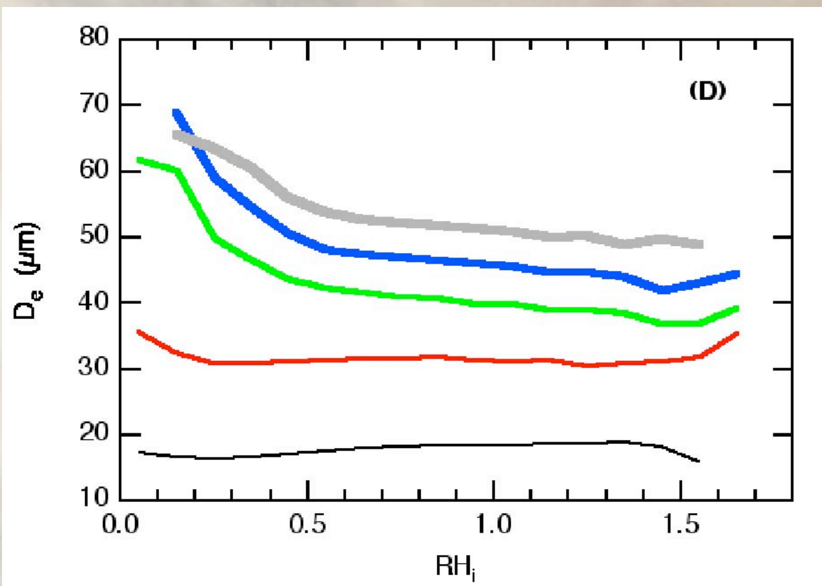


- **The answer is…definitely yes**
  - Tropical cases show lower RH_i and less variability

- **Coincident single-layer cloud thickness measured by CALIPSO and in-cloud RH_i**

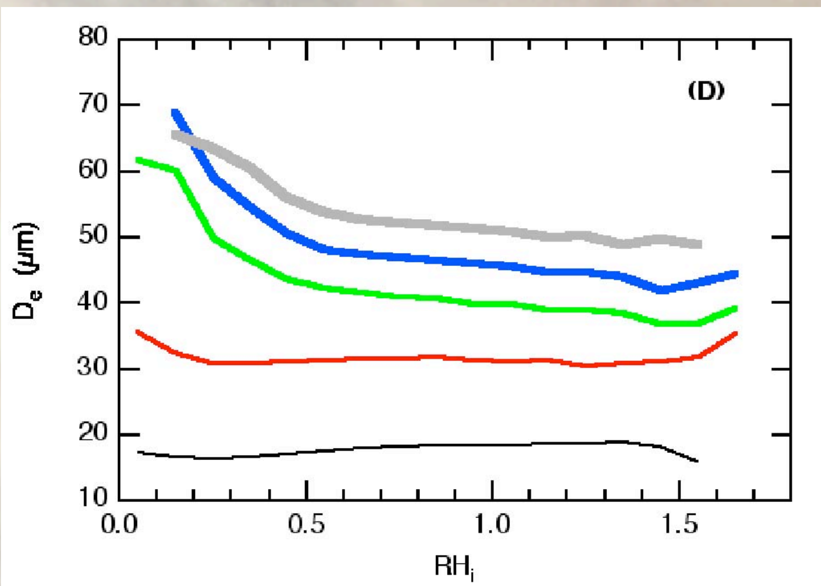
- **In-cloud RH_i distribution broader than should be for low RH_i**

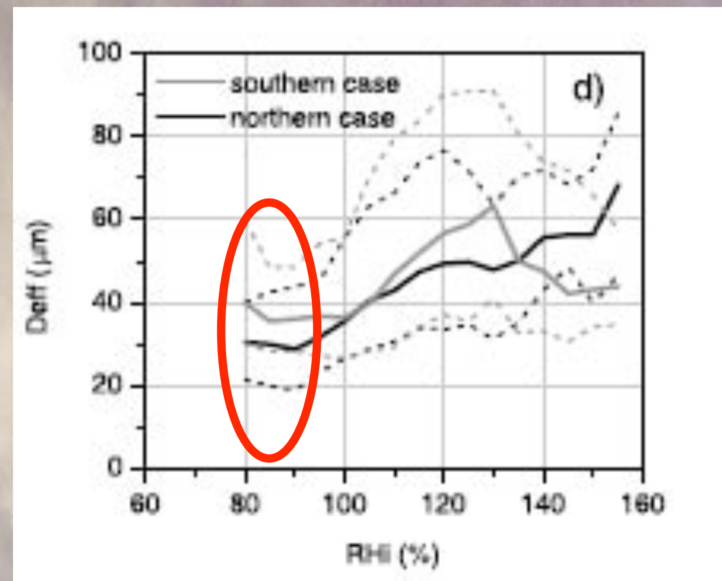
RH_i versus D_e: Why a correlation?



Larger ice particles survive in sub-saturated environment?

RH$_i$ versus D$_e$: Why a correlation?





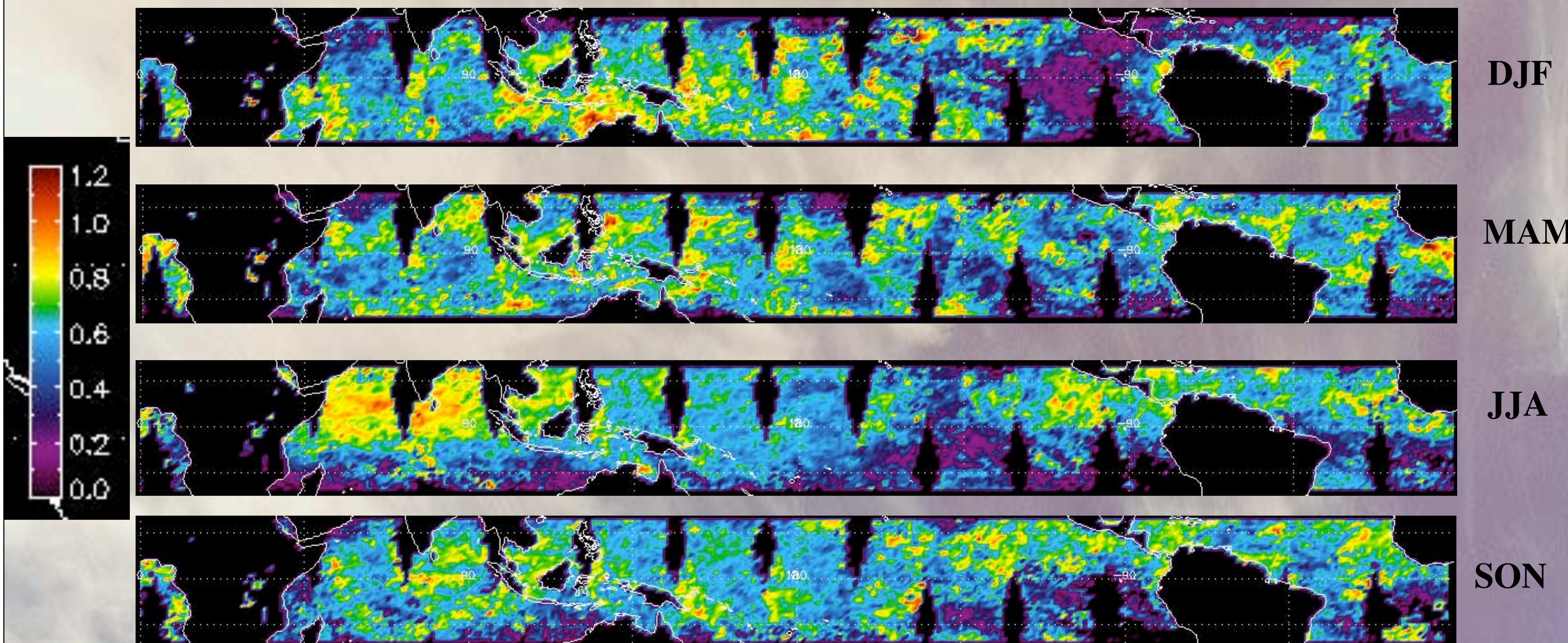
Gayet et al. (2004)

Observations from INCA campaign

A hint of same dependence?

Big differences in supersaturated conditions

Seasonal Variation of in-cloud RH_i



“Take Home” Messages

- **Retrievals consistent with other satellite, *in situ*, and surface obs**
  - Vertical distribution reasonable (refer to JGR and ACPD papers)
  - Increasing $\tau \rightarrow$ increasing D_e
  - Quantified biases due to RTM inputs
    - Produce spurious retrieval “modes” for thinnest cirrus

- **Simultaneous in-cloud RH_i and microphysics new capability from satellites**
  - 8–12% in-cloud supersaturation
  - Peak frequency 60–80%, biased low compared to *in situ* obs
  - Slight dependence of distribution of $RH_i > 1.2$ with τ
    - Heterogeneous/homogeneous nucleation differences?
  - For $\tau > 0.25$, RH_i distribution generally insensitive to minimum AIRS q(z) sensitivity
  - Low bias in RH_i correlate with cloud thickness (from CALIPSO)
  - Seasonal, latitudinal variability of in-cloud RH_i distributions

- **Importance of scene-dependent error estimates!**

Future Work

- **A larger data sample**
  - Optically thicker clouds, more complex configurations
  - Latitudes outside of tropics
- **Focus on CloudSat/CALIPSO track for combined retrievals/comparisons**
  - Group by cloud-type
  - Trajectory models to study air parcel history, in-cloud versus clear sky differences
  - Heterogeneous/homogeneous nucleation questions?
- **Further improvement of AIRS cloud fields**
  - Further refinements in retrieval algorithm, stress focus on high cloud and UT RH
  - Trustworthy error estimates for all quantities of concern
    - Regional and temporal variability in cirrus properties: Can they be believed?

All cloud photos taken from www.australiansevereweather.com